Center for Advanced Power Systems

November 2002, P.G. McLaren

ACADEMIC PROGRAM

- Offer graduate courses on power topics.
- Offer a new curriculum over 5 years which will lead to an MS/BS in power engineering
- Break down the barriers between ME & EE to permit course work in both departments.
- Once our simulation and testbed facilities are in place offer Continuing Education courses.

Program Resources

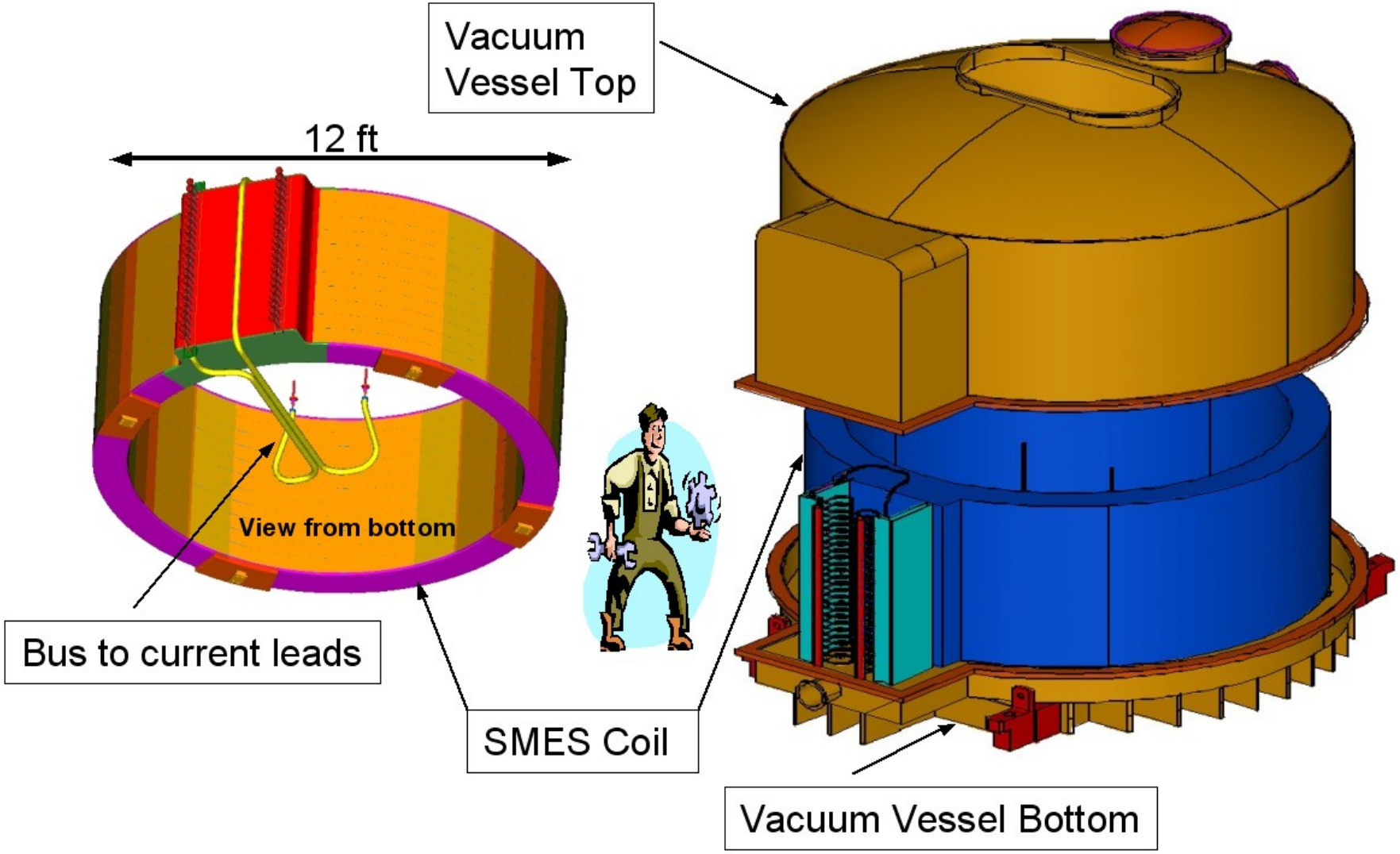
- National High Magnetic Field Laboratory
  - Superconductivity
  - Electromagnetic Analysis, Design & Experimentation
- College of Engineering
  - Multi-discipline
- School of Computational Science and Information Systems
- Institute for Science & Public Affairs
  - Economics
- 100 MW Dedicated Substation
- Cooperative Utility

CAPS Research Infrastructure

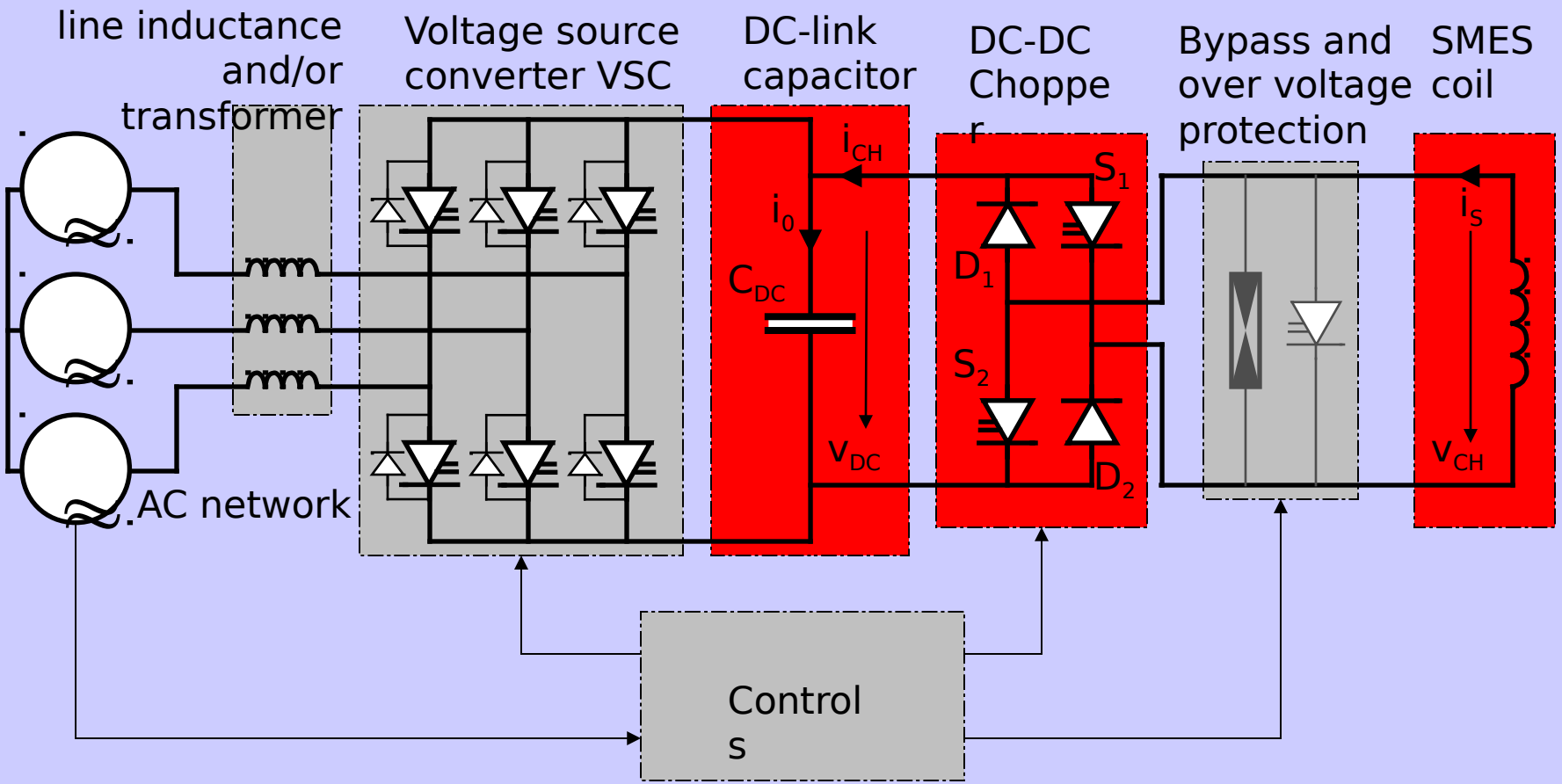
CAPS is developing a set of tools and apparatus:

- Superconducting apparatus HTS transformer, SMES
- Superconducting Materials Characterization capabilities at 27K including electrical, mechanical and magnetic properties_
- Simulation and modeling of electric power systems, both off line and real time.
- Component and system testing capabilities at 5 MW capacity level

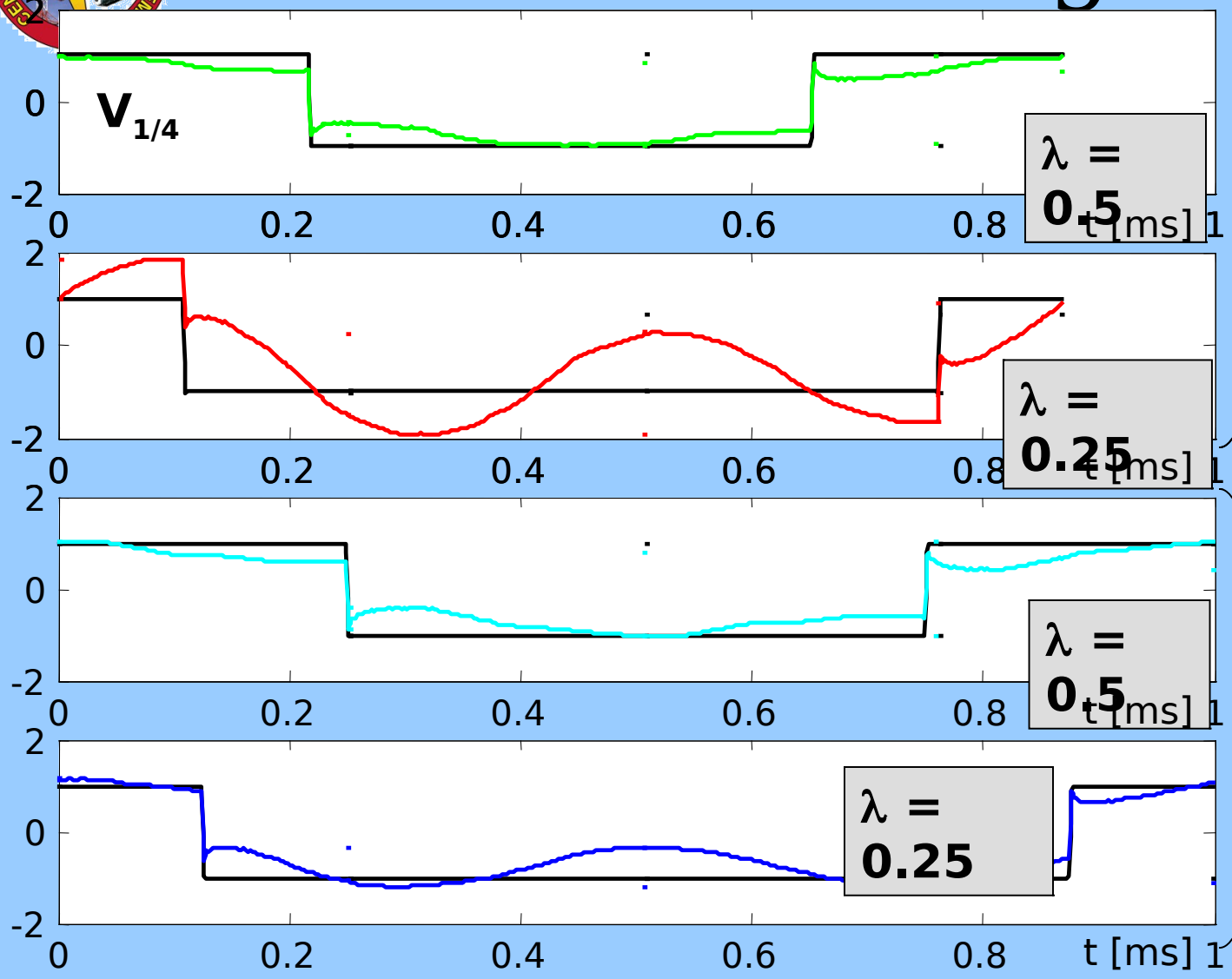
SMES Coil System



SMES Coil - Converter Interaction



Time Domain Signals



f_{CH} = 1.16 kHz

= 0.5

f_{s1}

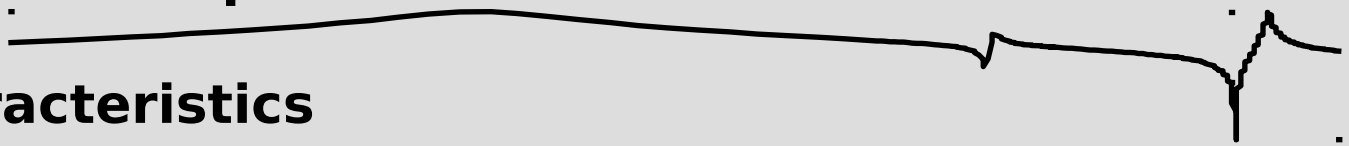
Excites first resonance with 2nd harmonic

f_{CH} = 1.00 kHz

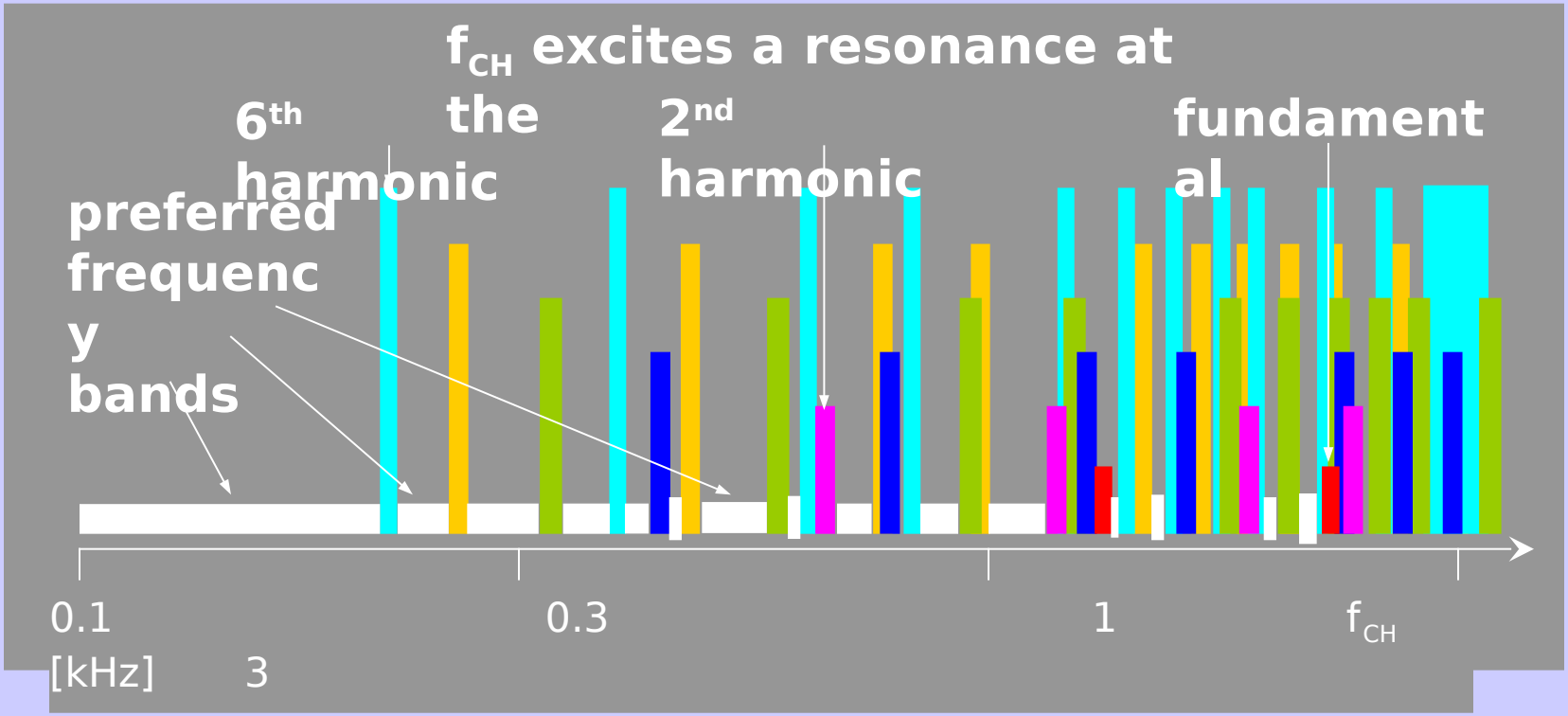
None of the harmonics match a resonance

Preferred Operating Frequencies

Terminal Impedance



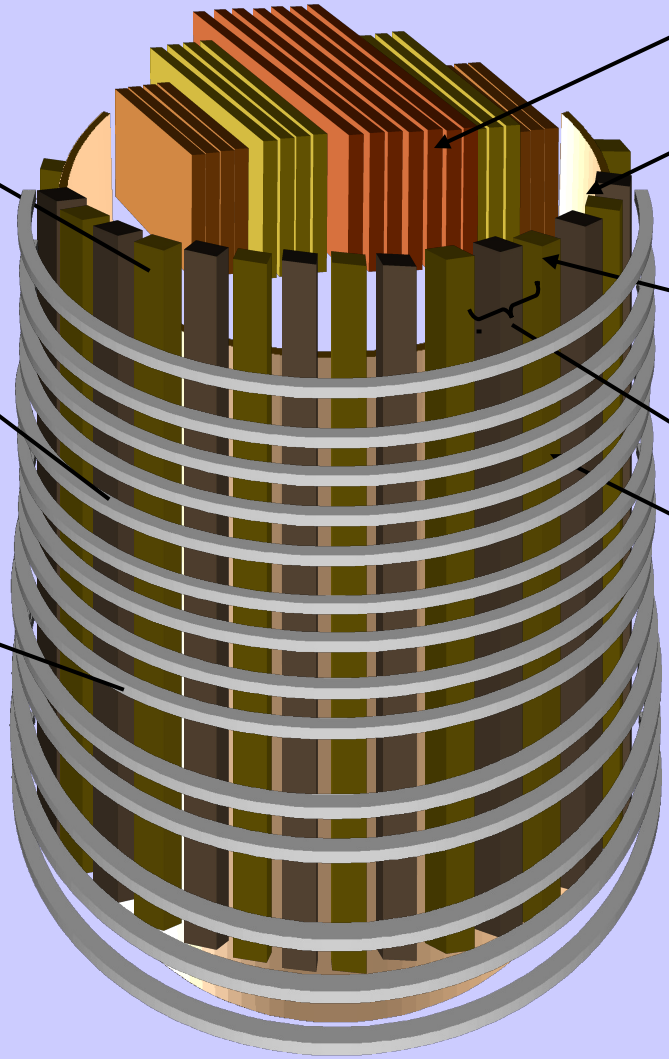
characteristics



CAPS HTS Transformer Project

- Objectives:
  - Identify transformer materials and designs that are appropriate for ship applications
  - Design, build, and evaluate a 3.5 MVA prototype transformer
  - Identify areas of technical needs and develop research programs leading to solutions
  - Transfer the new technology to the ship building / equipment manufacturing industries
  - Facilitate the expansion of the technology into the utility industry

Single Coil Cutaway View



stepped core

cryostat / winding form

copper cooling conductors

spacer

Bi-2223 HTS windings

cooling conductors connected to cold head of cryo-cooler

winding are electrically isolated from the cooling conductors

solid insulation fills all the voids within the coil winding

Representative only
Not to scale

- Design-Optimization Program
  - interactive design program based on MatLab (unix or pc platforms)
  - design program consists of synthesis, analysis, and optimization functions
  - 3-phase, 3- and 5-legged core, 500-kVA to 5-MVA power transformer designs
  - AC losses and stray field effects in the superconductor, and cryo-system are included in the analysis
  - cost optimization also includes the penalties for the losses, short-circuit impedance, and the total transformer weight and volume

Cooling Systems

All superconductors today require some type of cooling

- HTS materials are typically cooled in liquid nitrogen, 77 K
- Better HTS performance is obtained by cooler temperatures

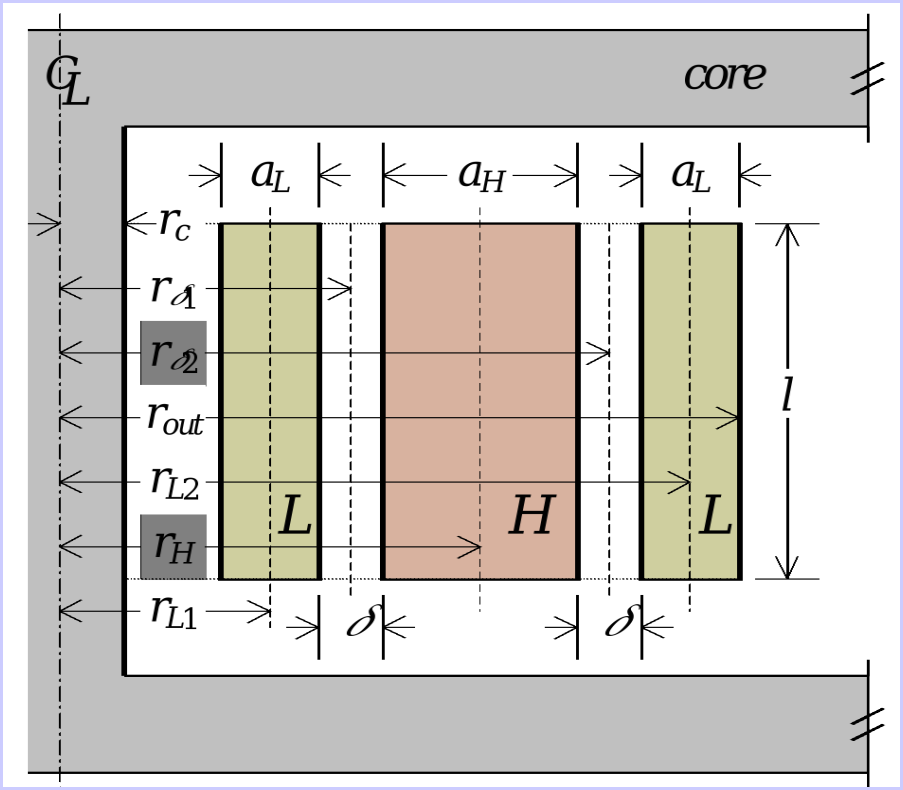
- Cooling technologies
  - Cryo-cooler
  - Liquid cryogens
    - closed and open loop systems
- Navy requirements prohibit the use of liquid cryogens
  - Safety issues
  - Cryo-coolers provide for mechanical or limited liquid cryo-refrigeration

Cooling of the Windings

- Performance of the conductors is temperature dependent
  - reduced AC losses at lower operating temperatures
  - penalized with increased cooling costs
- Optimize the thermodynamics
  - balance the compactness of the windings with efficiency of the cooling system
  - find optimum temperature that minimizes the overall power consumption
  - conduction-cooled concentric coil windings should operate between 65 K and 75 K
  - justify cooler temperatures only if AC losses are substantially reduced

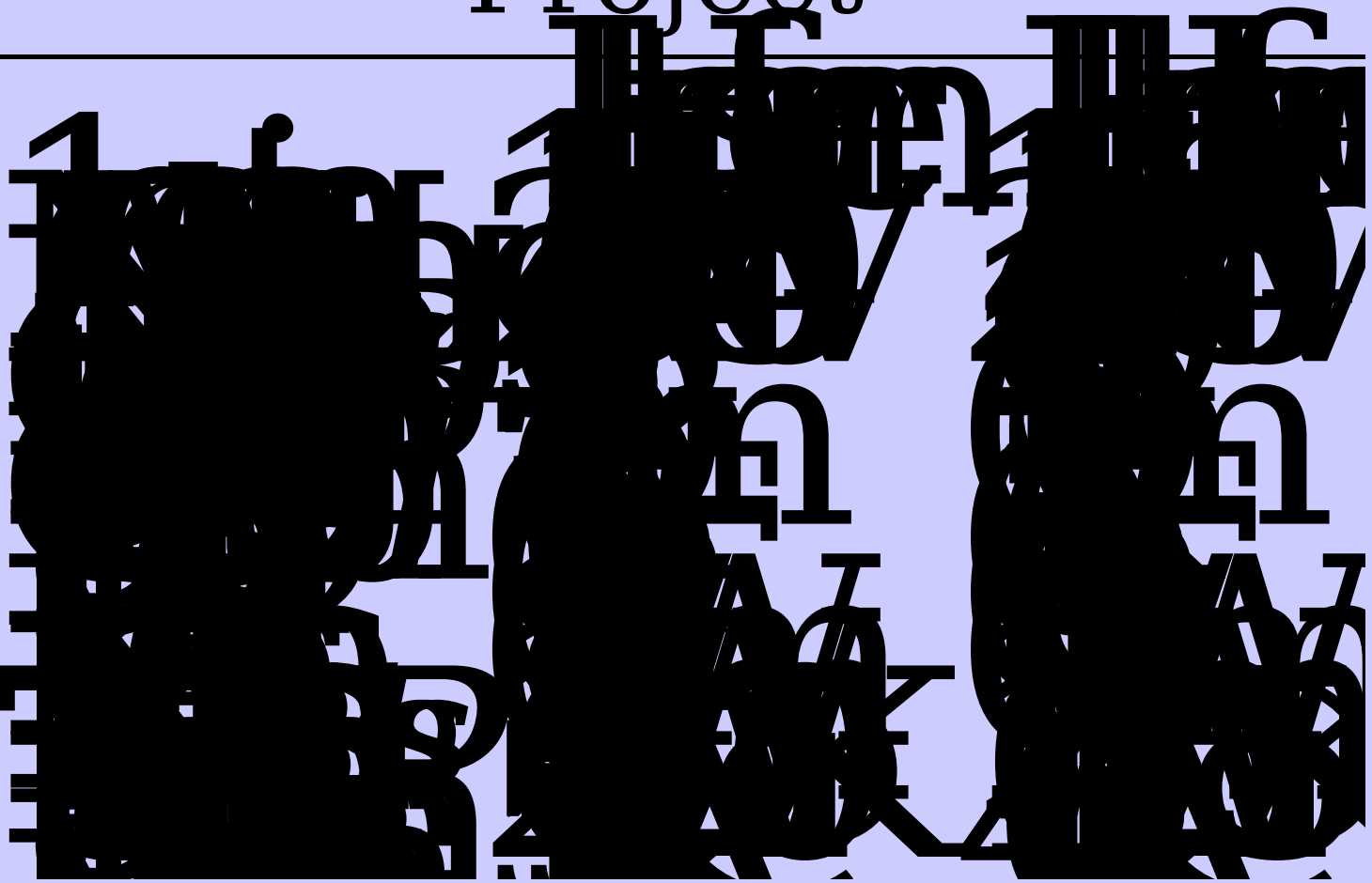
Leakage Impedance

- Leakage reactance makes up most of the transformer impedance
- impedance serves to limit the short-circuit current



$$x_{pu} = \frac{S_{Rating}}{V_{Rating}^2} \cdot \frac{(2\pi)^2 \mu_0 f N^2}{l + 0.16(r_{out} - r_c)} \cdot \left[\frac{a_L}{3}(r_{L1} + r_{L2}) + \delta(r_{\delta 1} + r_{\delta 2}) + \frac{a_H}{3} r_H \right]$$

CAPS HTS Transformer Project



Accomplishments to Date

- Creation of a technical report and paper database
  - website of engineering reports, conference and journal papers, and press releases covering HTS transformers and applicable technologies
  - website provided to SPD Technologies and Northrop-Grumman
    - http://www.eng.fsu.edu/~tbaldwin/caps/htst/

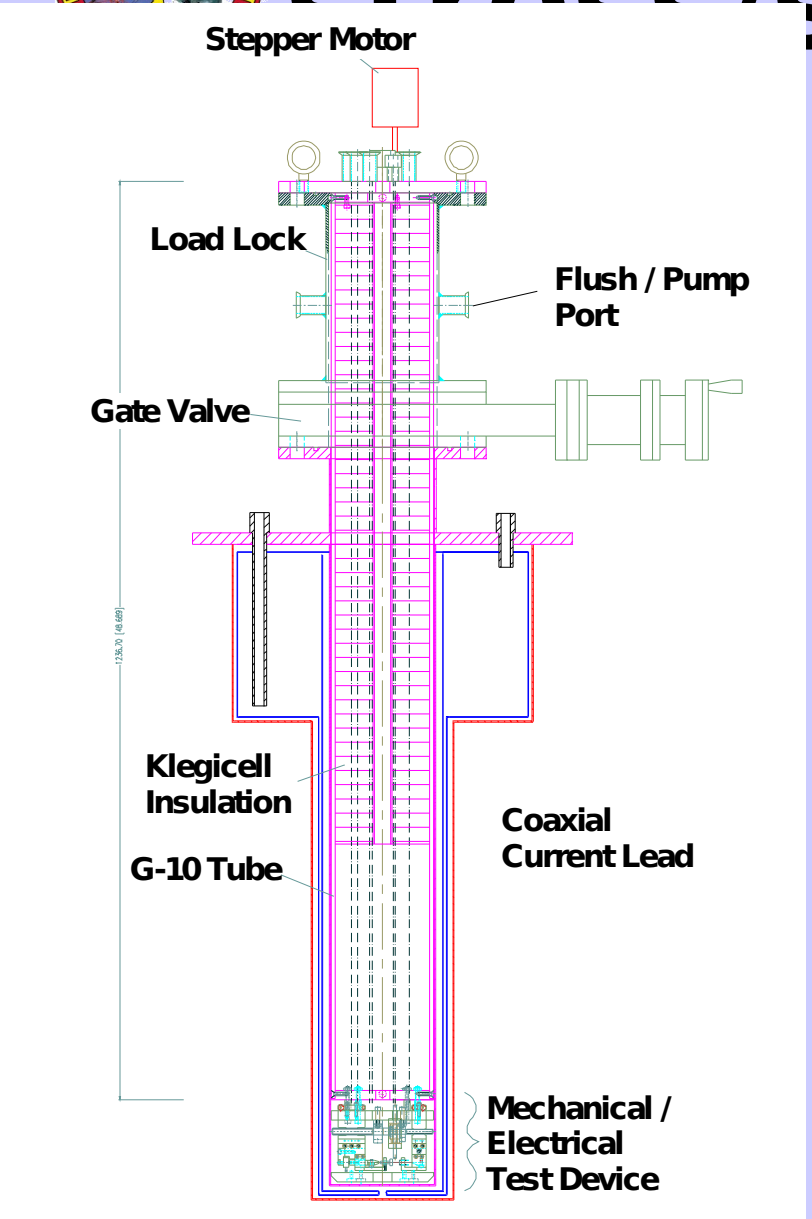
Accomplishments to Date

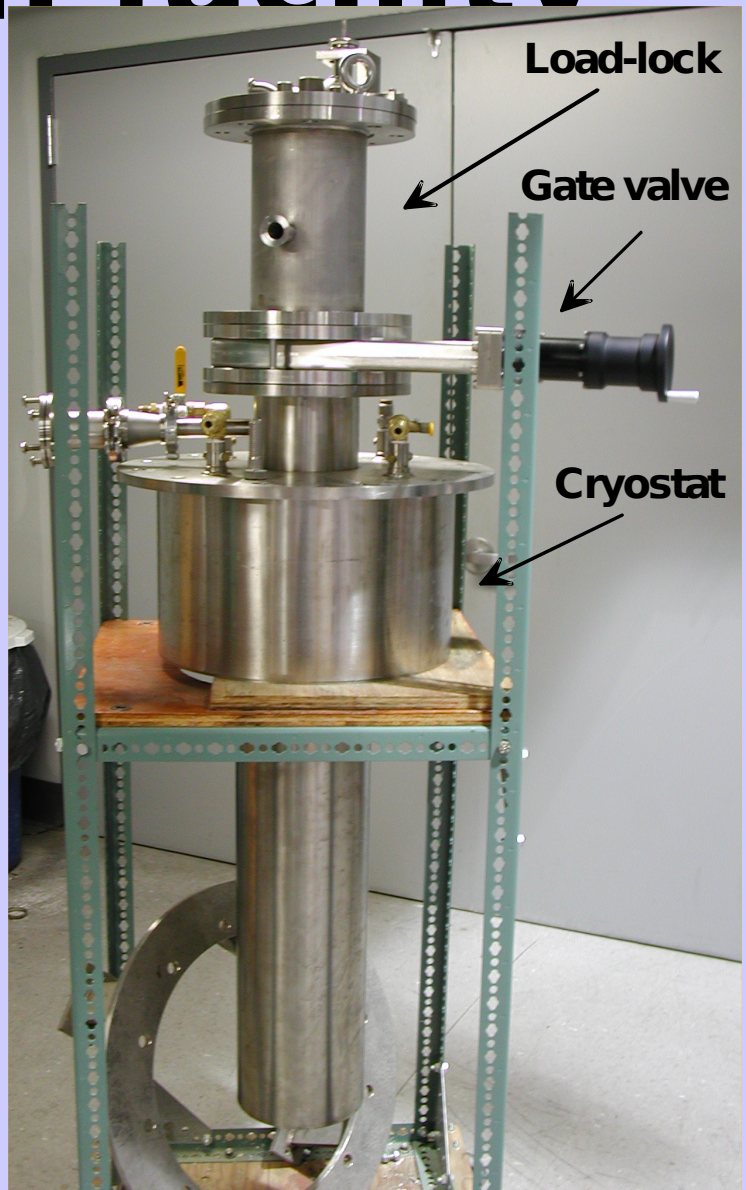
- ASC 2002 Conference Papers
  - Cryogenic cooling temperature of HTS transformers for compactness and efficiency – Chang, Choi, Van Sciver, Baldwin
  - Design optimization of high-temperature superconducting power transformers – Baldwin, Ykema, Allen, Langston
- Student Projects
  - Rebuilding a Westinghouse 25kVA pole top transformer with HTS windings

Outline

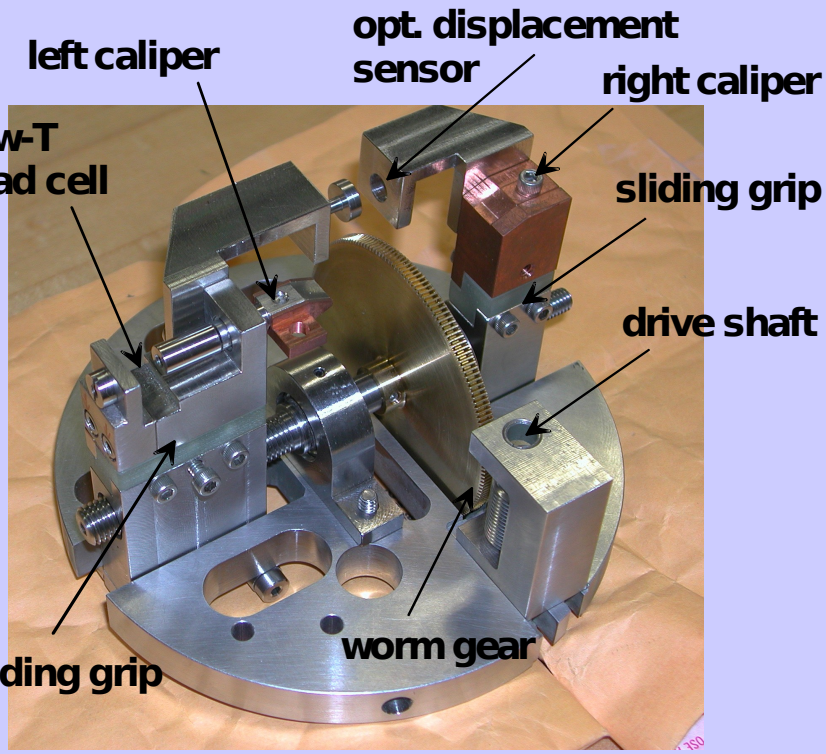
- High temperature superconductors are entering the marketplace
  - Ag-alloy clad, multifilamentary wires of $Bi_2Sr_2Ca_2Cu_3O_x$
- American Superconductor Corporation is investing 85M$ in manufacturing
  - hardware is on the floor
  - first test-billet is presently in the system
- Motors, generators, transformer, cable development projects are on-going
- Engineering perspective:
  - critical current density (J_c) is more than sufficient for many applications
  - engineering data exists for single-cycle mechanical behavior
  - tensile properties acceptable (stainless-steel reinforcement)
  - mechanical behavior under axial compression not fully understood
  - fatigue behavior not well-studied or understood
- AC losses are a key issue for engineering/economics of AC applications

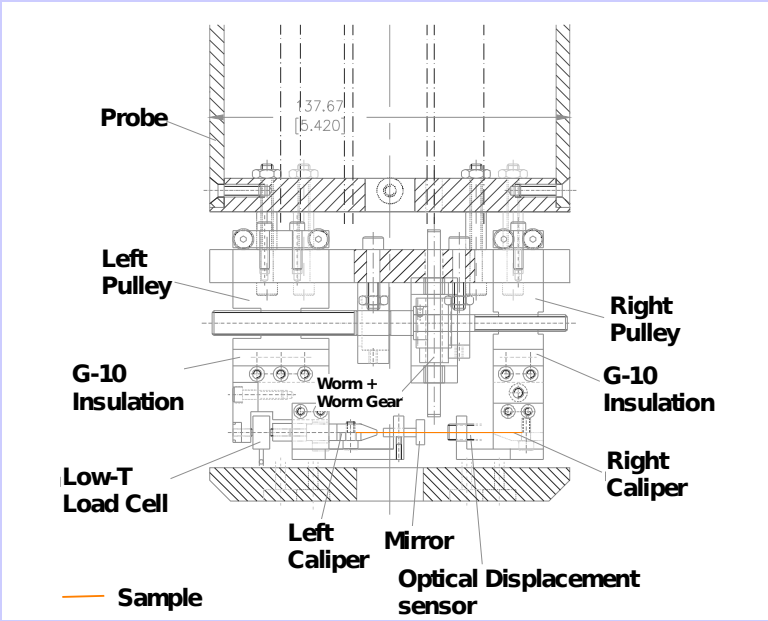
Low temperature stress/strain facility





Electromechanical test device





HTS Conclusions

- CAPS HTS materials R&D focusses on issues that are particularly important for power systems
  - mechanical effects on performance and lifetime
  - low AC loss conductor development
  - AC loss measurement facilities
- CAPS HTS program will couple directly to larger projects
  - Motors, generators, transformer (next talk)
  - Specific experimentation driven by needs of specific device projects

HTS Conclusions cont./

- CAPS benefits from significant HTS programs within the NHMFL
  - NHMFL high field insert coil R&D (with industrial partner)
  - DoE funded research on stability & quench propagation
  - AFOSR funded research on magneto-optical imaging and micromechanics

Simulation and Modeling

- Bring Utility Simulation and Modeling to the Marine Industry
  - Demonstrate Simulation Capability
  - Compare Simulation with Actual Data
- The Healy Program was our first activity
  - Demonstrated Ability to model complex electromechanical system with Utility simulation platforms
  - Worked with industrial partners on the program
- Next step is to develop real-time, hardware-in-the-loop simulation capability

Initial Simulation Project: Healy

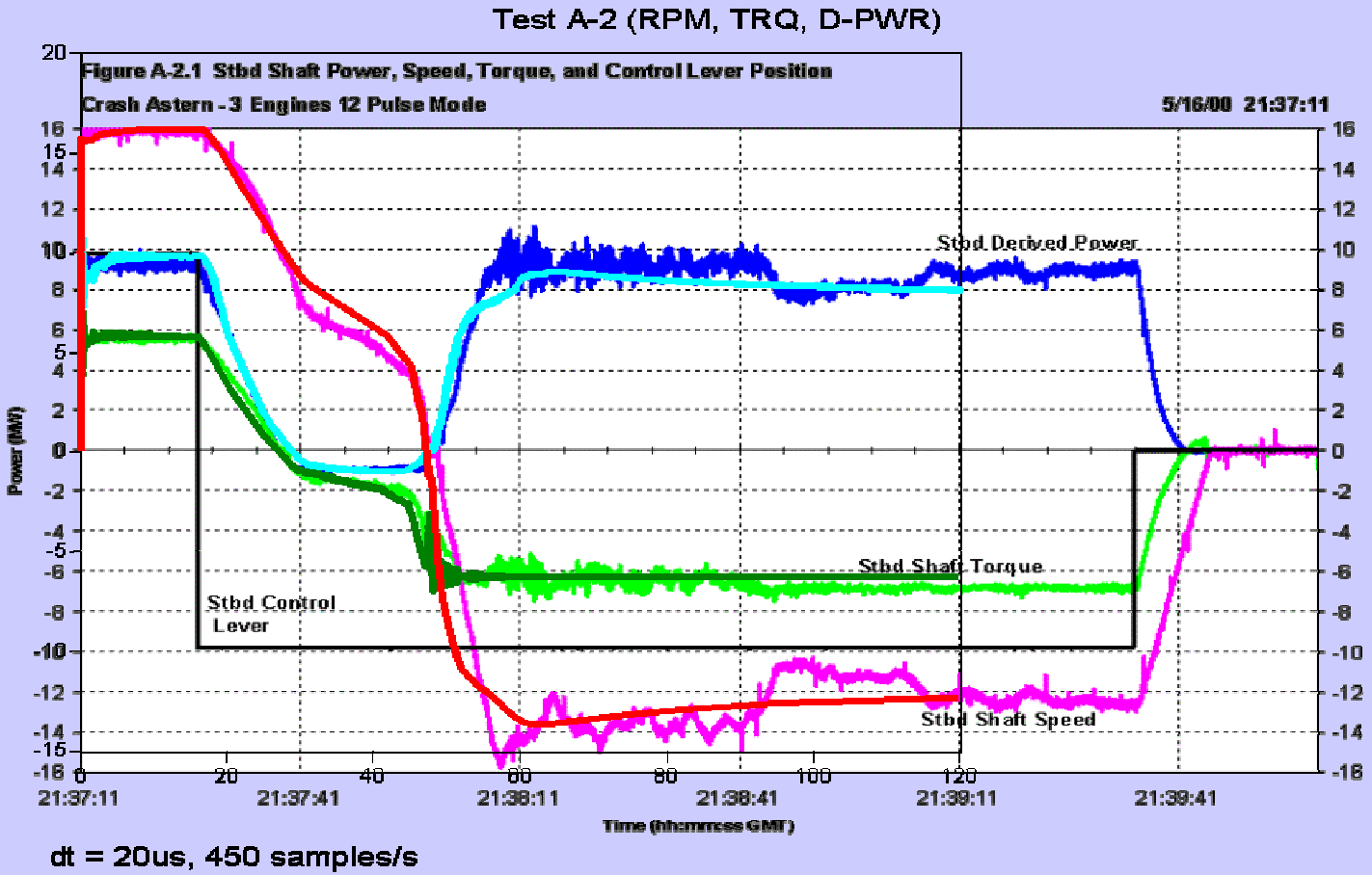
Existing Software ⟺ **Operational Ship**

Partners

Software

Validation/Expertise

USCGC Healy



Capability for simulating marine propulsion systems demonstrated.

RTDS

RTDS Simulation - Hardware

NEW Processing Card

Risc Processor Card - R*PC*:

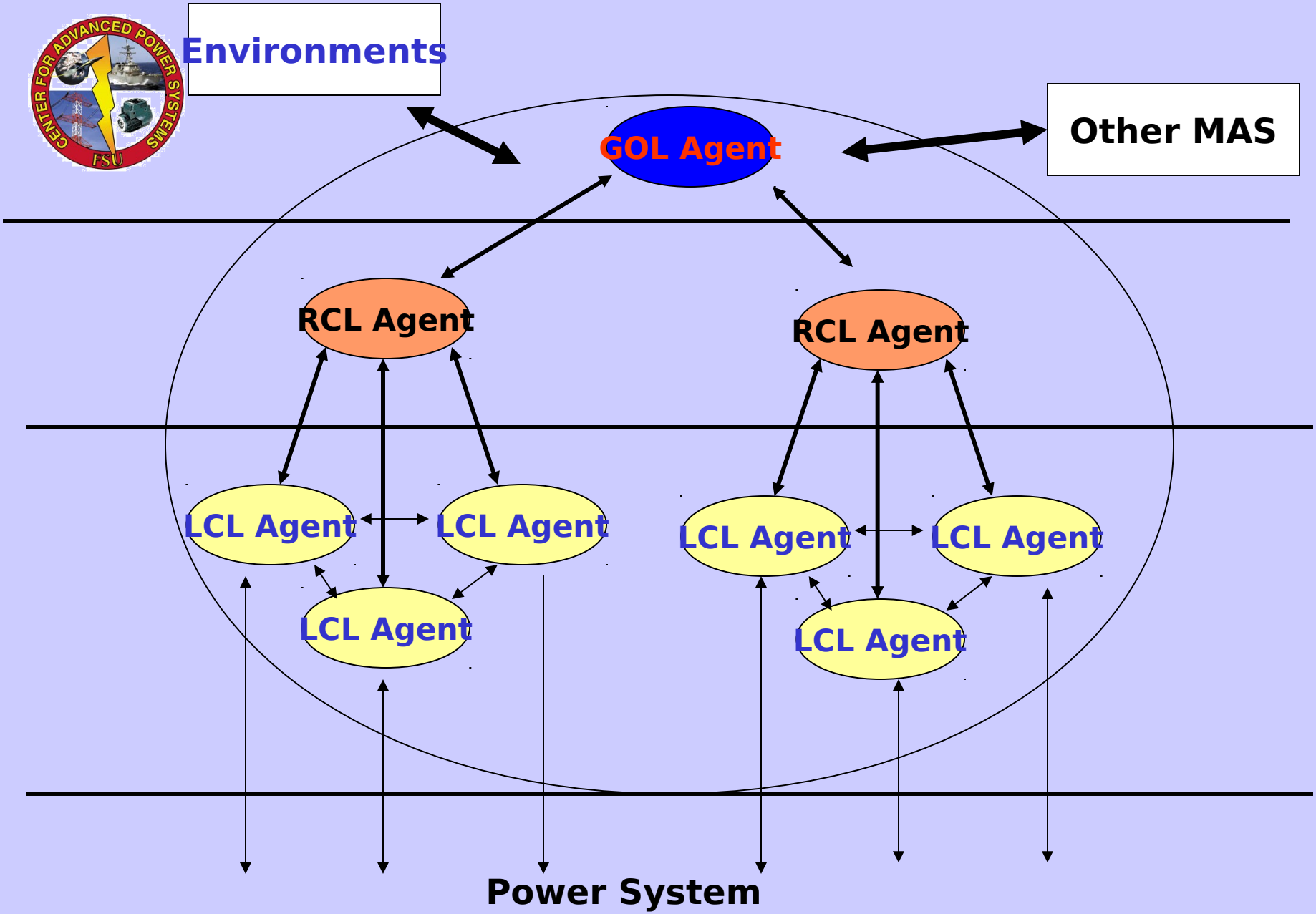
	TPC	3PC	**RPC**
Processor	NEC D77240	ADSP 21062	**IBM PPC750CXe**
Precision	55-bit	40-bit	**64-bit**
Processors per card	2	3	**2**
MFLOPS per processor	11	80	**600**
MFLOPS per card	22	240	**1200**
(MFLOPS = millions of floating-point operations per second)			

To be release Fall 2002.

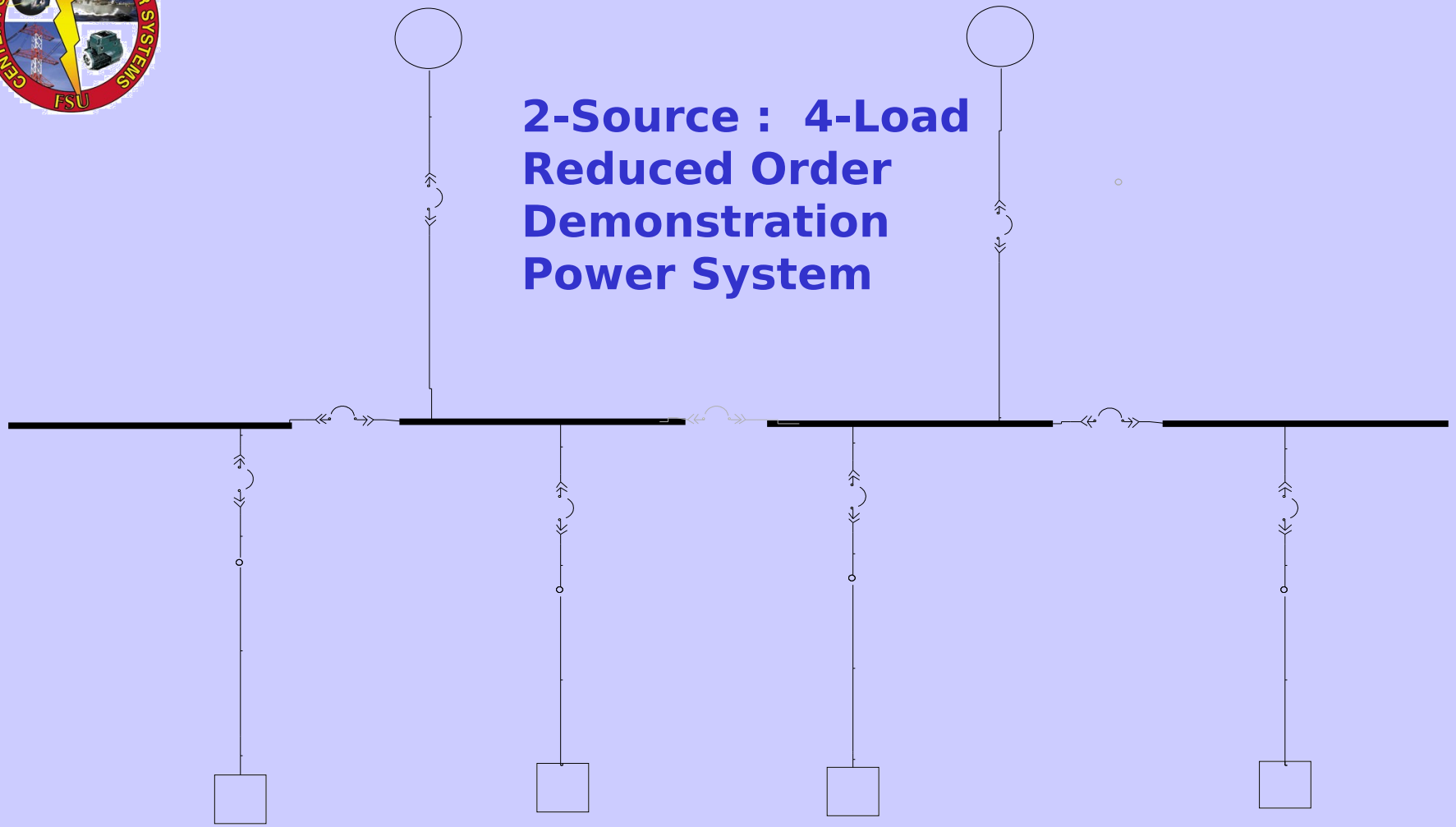
RTDS Technologies

Schedule

- ✓ RFP (February 2002)
- ✓ Proposals Received and Evaluated (Marc
- ✓ Award Made to RTDS Technologies (April
- ✓ Delivery and Acceptance Tests (Septemb
- o Familiarization and Low-Power Test Bed Experimentation (September 2002 -- Mi
- o Integration with 5 MW Test Bed (Mid 200


Environments
GOL Agent
Other MAS
RCL Agent
RCL Agent
LCL Agent
LCL Agent
LCL Agent
LCL Agent
LCL Agent
LCL Agent
Power System

Example: 1st Year Problem, a Proof of Conc

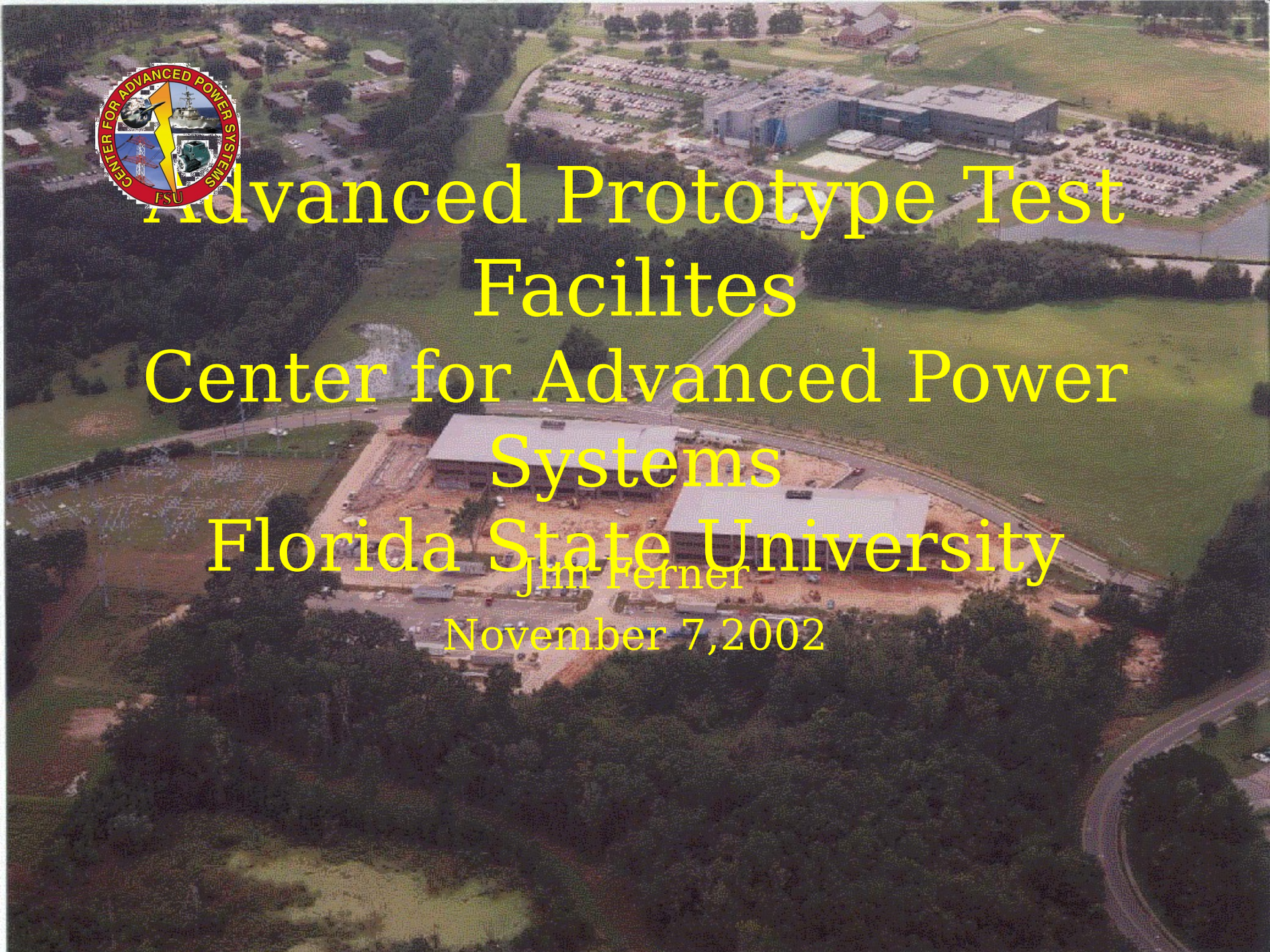


Ultimate aim

- Build prototype control system based on mobile agents.
- Interface the actual controller to the model of the ship power system running on the RTDS.
- Run various scenarios to test the overall system control

Institute for Science & Public Affairs

- Economics of dual use.
- Risk management



Advanced Prototype Test Facilites
Center for Advanced Power Systems
Florida State University

Jim Ferner

November 7,2002

Objectives of Power System Research at CAPS

- Develop a sound understanding of the interaction of components
- Develop the ablity to predict the performance of new technologies inserted into existing systems.
- Develop new system concepts

CAPS Observations

- Facilities for hands on training of young engineers in power system technology are extremely limited.
- Capabilities for real-time simulation and hardware-in-the-loop evaluation at prototype level are very limited
- Locations and resources for long-term operating demonstrations of new technologies and their integration into power systems are essentially non-existent.

CAPS Response

Undertake a program to develop Advanced Prototype Test Facilities with up to 5 MW capability:

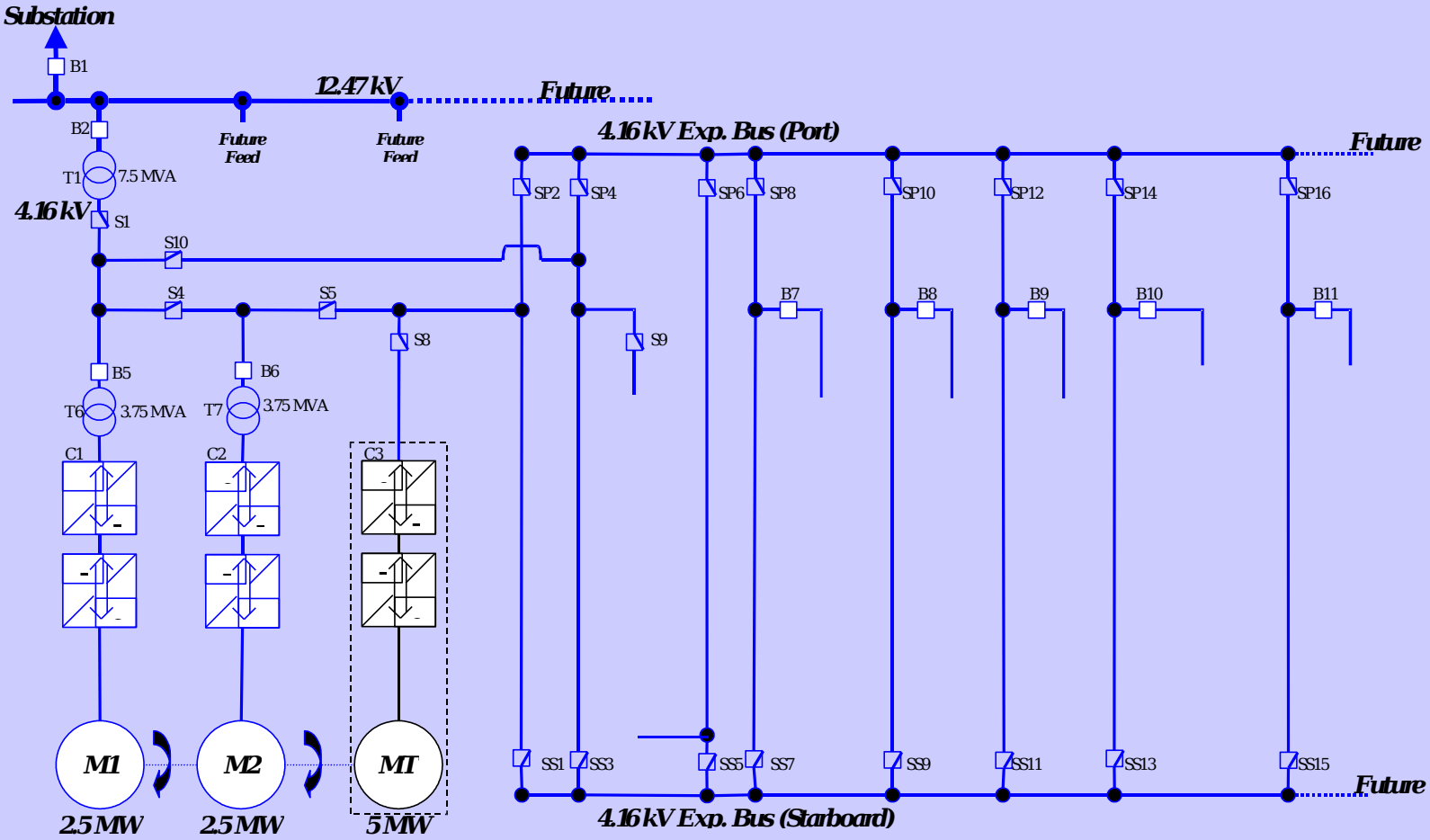
- 5 MW dynamometer for dynamic testing of motors and generators
- Variable frequency, variable voltage AC source to simulate ship system sources.
- Variable voltage DC to simulate ship system sources
- Pulsed load and energy storage capability
- On-site generation to emulate isolated facilities
- Integrate with real-time simulation and H-I-L environment to emulate extended systems.

Facility Development Program

The Advanced Prototype Test Facilities are being developed in phases based on availability of funding:

- Phase 1 – Machine Test Dynamometer
- Phase 2 – Variable AC Bus
- Phase 3 – DC Bus System
- Phase 4 – Pulsed power load and source, energy storage capability
- Phase 5 – On site generation

Phase 1 – Machine Test Dynamometer



Machine Test Capability

Dynamometer-

- 2 - 2.5MW induction motor drives
- Fully reversible and regenerative drives
- Low inertia to maximize controllable range

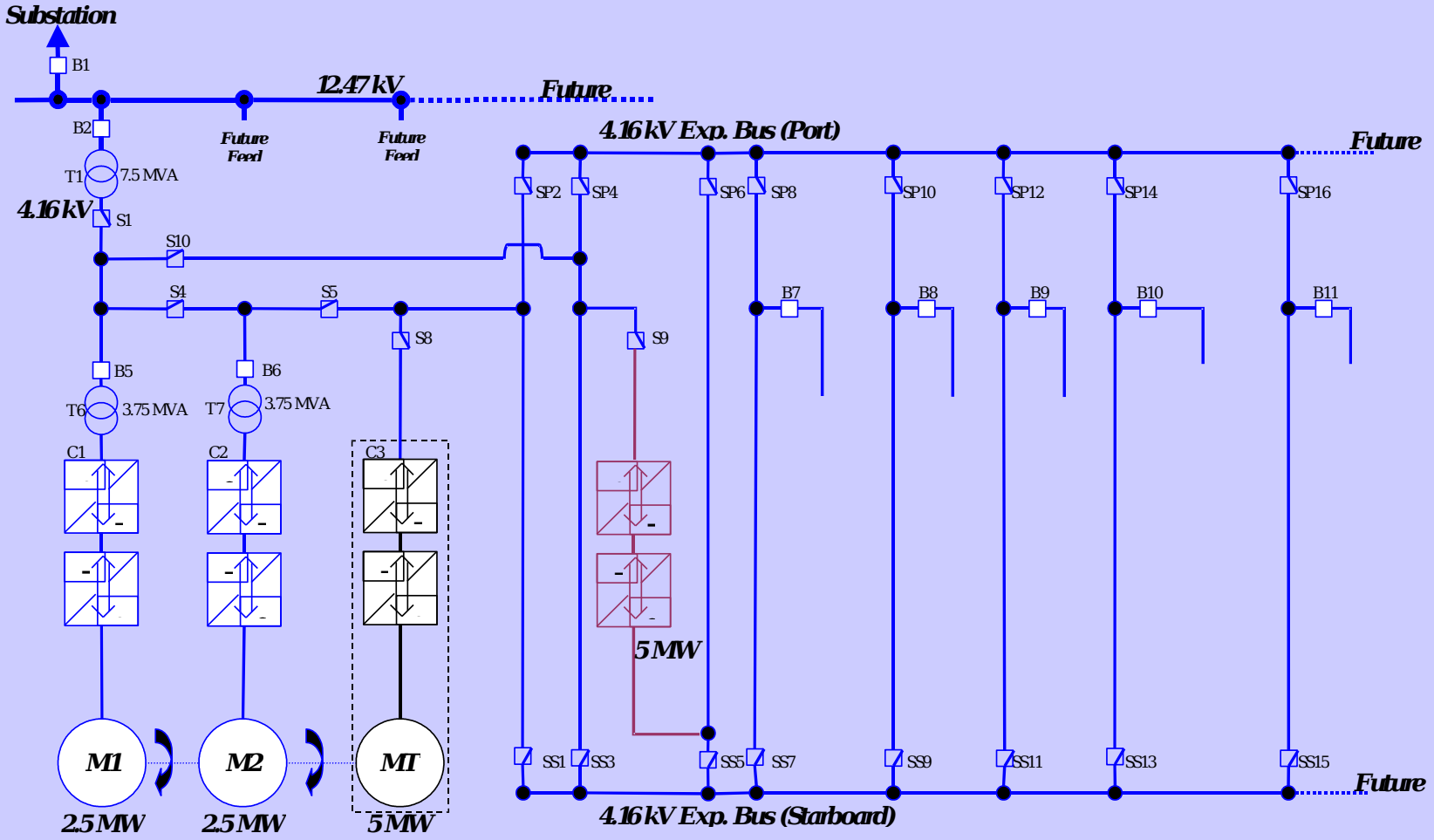
Operating Modes –

- Stand-alone MG set for study of controls and drives, emulation of drives in power systems for interaction with other devices
- As dynamometer – 5 MW capability for test of prototype motors and drives or generators – can represent regenerative loads

Status –

All equipment is on order and scheduled for delivery in first half of 2003

Phase 2 – Variable AC Bus



Variable AC Bus Capability

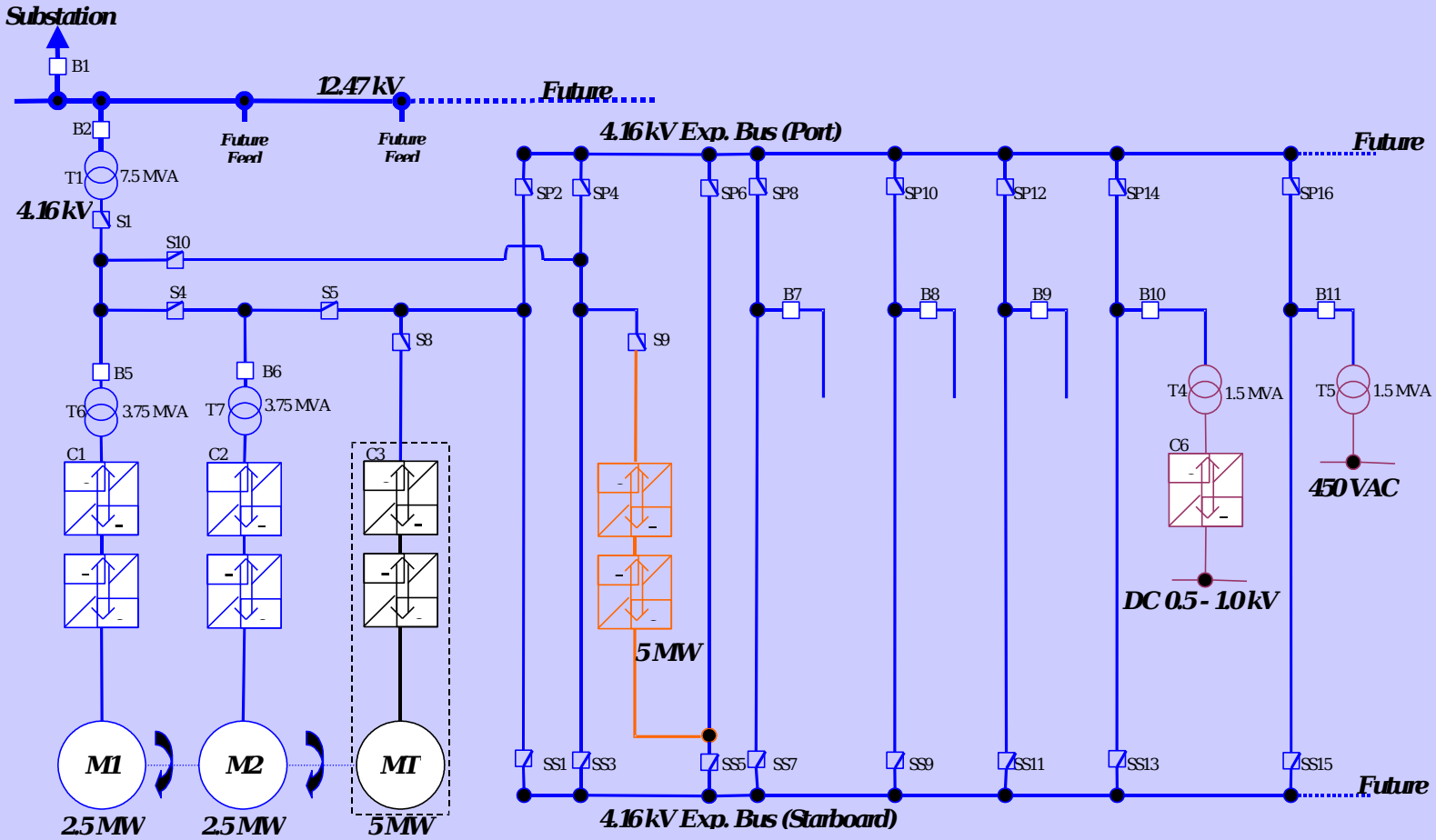
System Capability

- 5MW Power Capability – fully regenerative
- Bus voltage and frequency controllable
- Voltage Range – up to 5KV, 3 phase
- Frequency Range – 10 – 120 Hz
- Ranges to be determined in part by procurement process.

Status

- Procurement specifications being developed
- Procurement scheduled for mid 2003
- Installation by end of 2003

Phase 3 – DC Bus System



DC Bus System

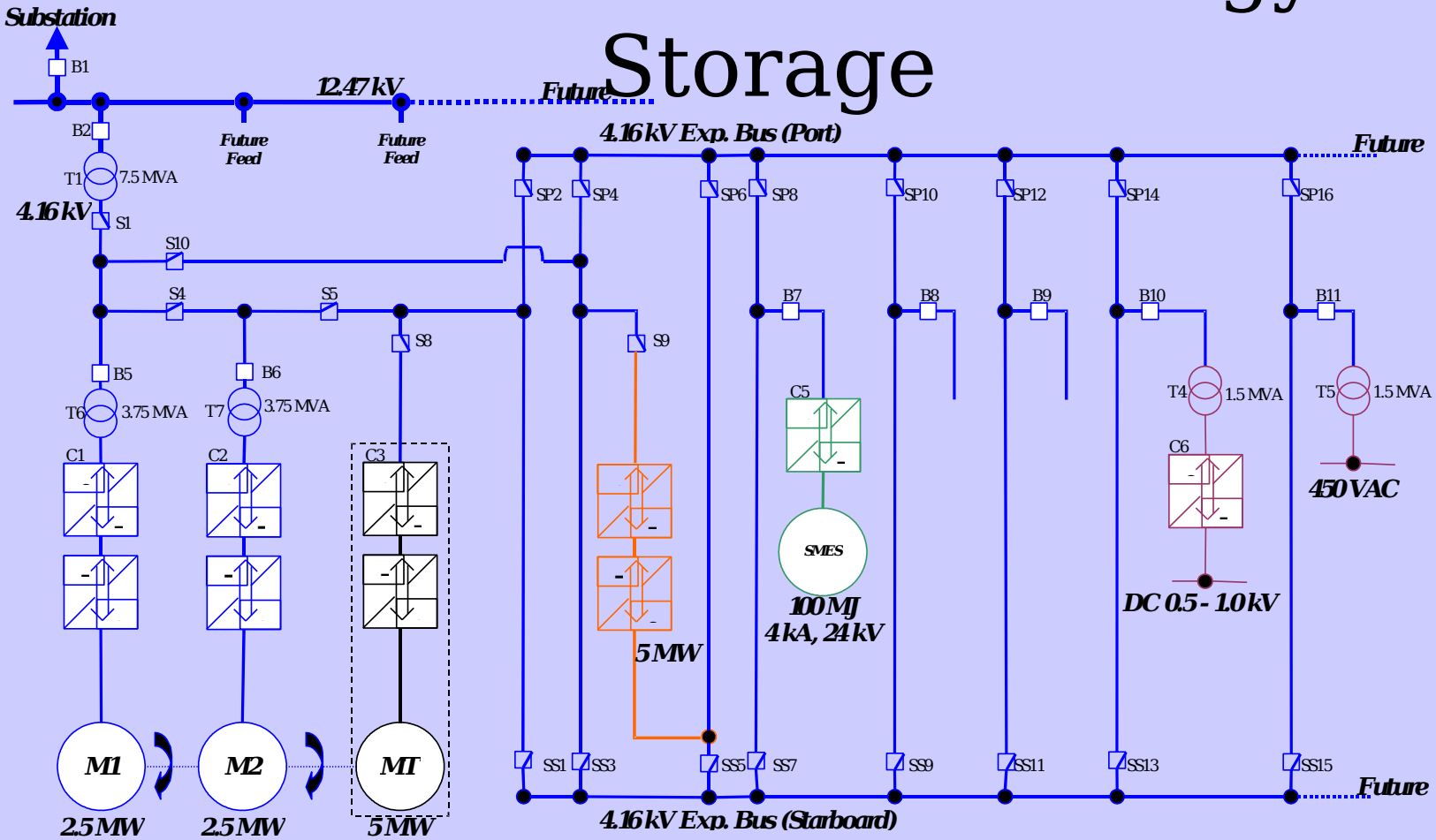
Provides a capability to investigate interactions with DC systems:

- Fully regenerative, 500 to 1000 volt DC converter, at least 1 MW capacity, controlled voltage.
- 450 Volt un-regulated AC bus which can be supplied through the variable AC bus or other sources.

Status:

- System in preliminary design
- Scheduled for procurement and installation in 2004

Phase 4 – Pulsed Power and Energy Storage



Pulsed Power & Energy Storage

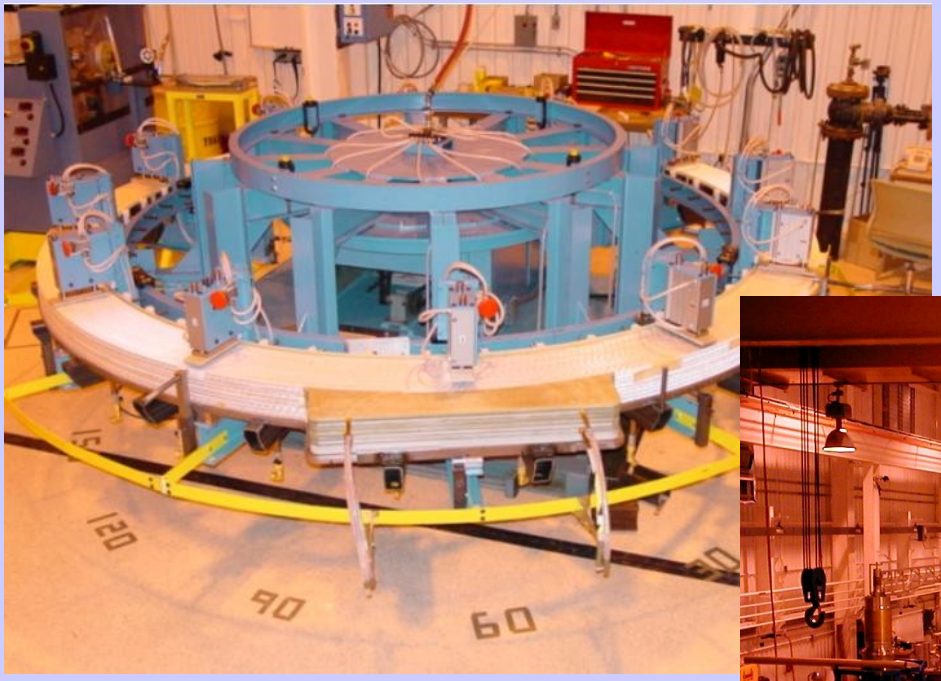
System Components

- 100 MJ Superconducting Magnet for energy storage – designed for 90MW maximum discharge, +/- 50MW at 3 Hz for 15 seconds.
- Converter – DC Chopper + PWM inverter, bi-directional, 5 MW capacity.

Functions

- Energy Storage – simulate batteries, inertial, capacitors
- Pulsed Supply/Load Simulation – at least 5MW pulses

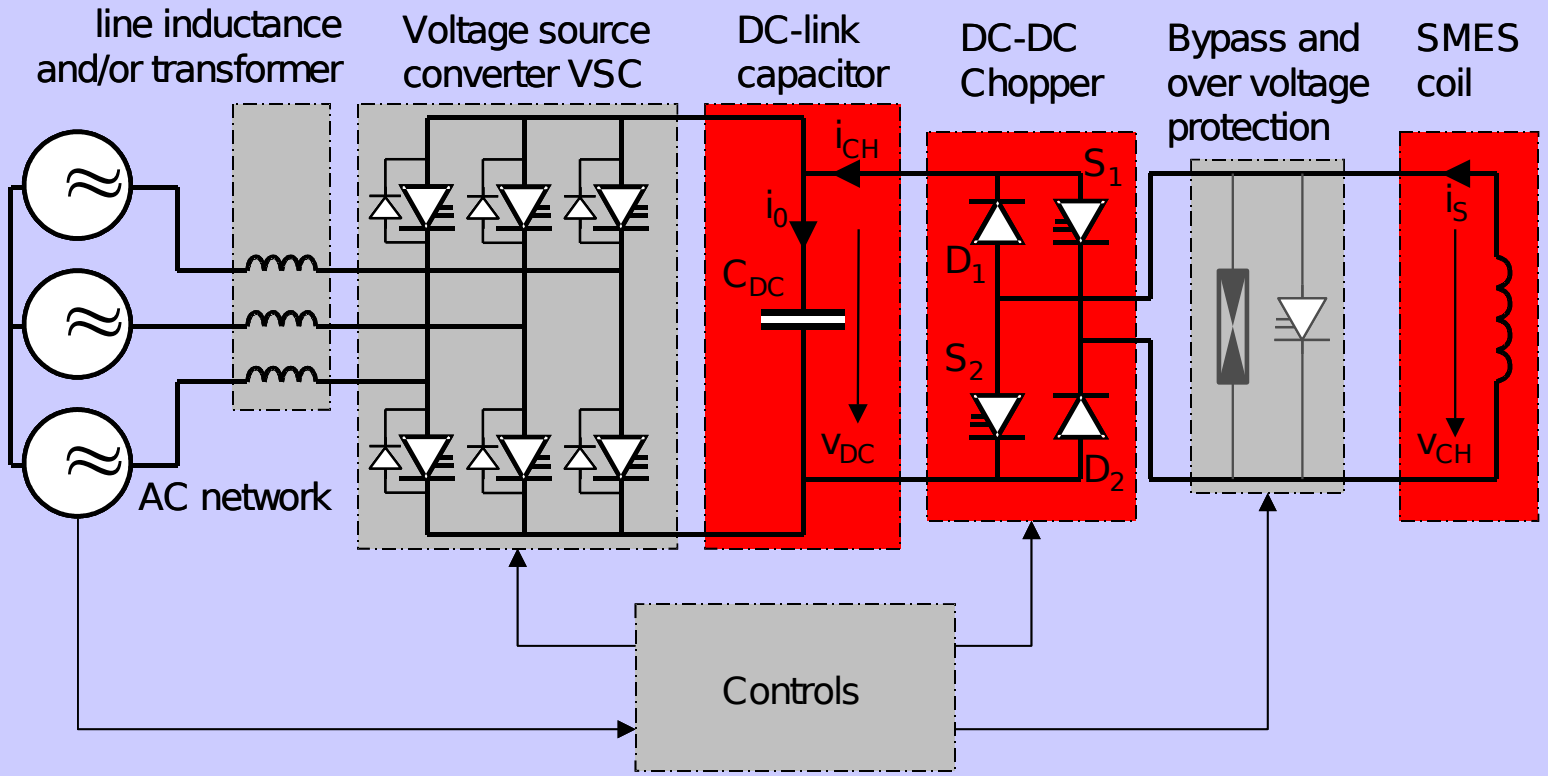
Energy Storage Status



Coil Winding Fixture

Fabrication Facility

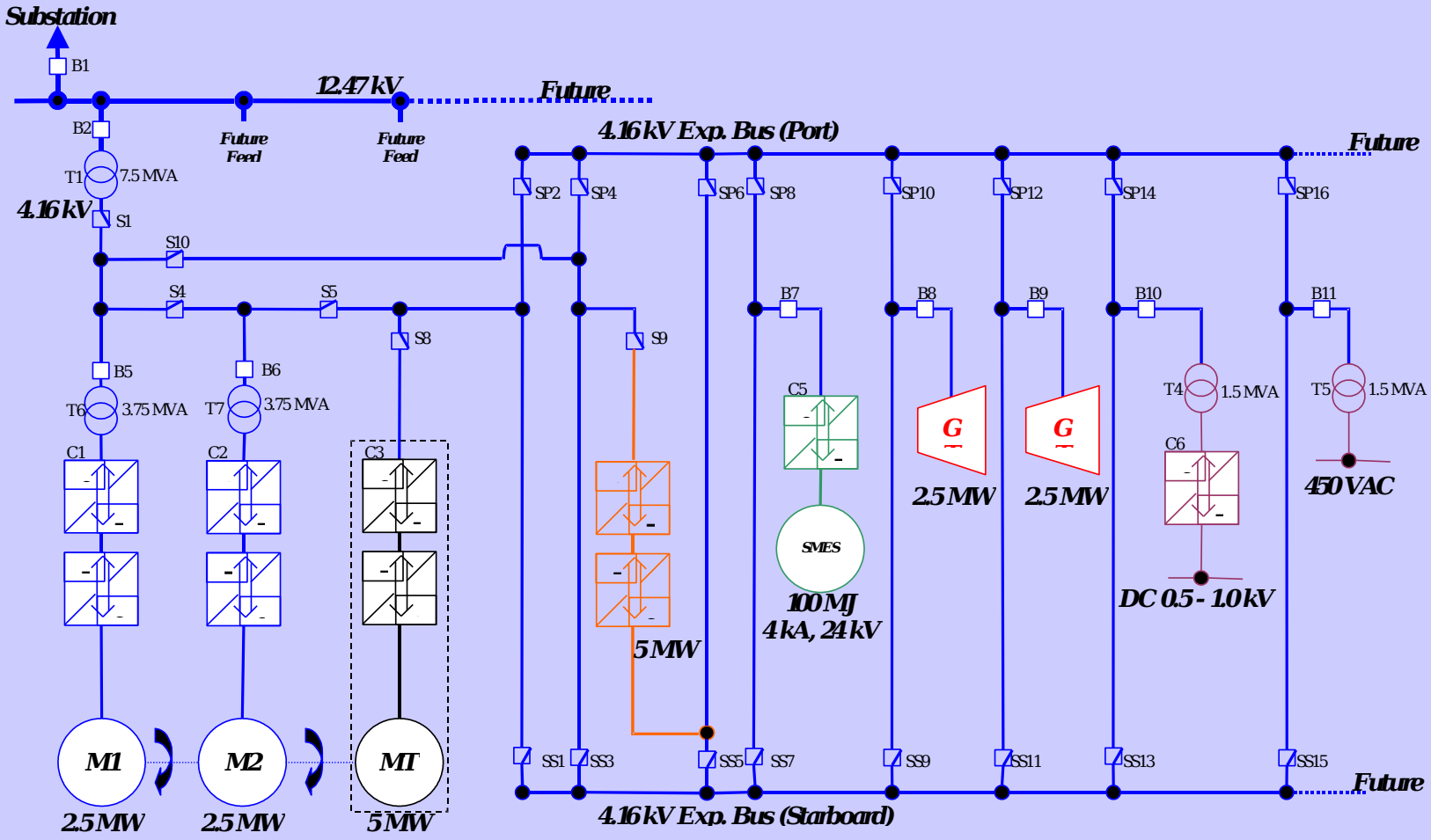
Power Converter Concept



SMES Status

- Coil completed summer 2003
- Cryostat Design – In process, Procurement in early 2003
- Magnet Assembly – Scheduled for second half 2003
- Cryogenic System – Design in process, procurement 2003, 2004.
- Converter R&D – In process, Procurement in 2004
- Installation complete – 2004-2005

Generation


Substation
B1
12.47 kV
Future
B2
Future Feed
Future Feed
4.16 kV Exp. Bus (Port)
Future
T1
7.5 MVA
4.16 kV
S1
S10
SP2
SP4
SP6
SP8
SP10
SP12
SP14
SP16
S4
S5
S8
S9
B7
B8
B9
B10
B11
B5
B6
T6
3.75 MVA
T7
3.75 MVA
C1
C2
C3
C5
G
G
T4
1.5 MVA
T5
1.5 MVA
C6
SMES
100 MJ
4 kA, 24 kV
2.5 MW
2.5 MW
450 VAC
DC 0.5 - 1.0 kV
5 MW
M1
M2
MT
2.5 MW
2.5 MW
5 MW
SS1
SS3
SS5
SS7
SS9
SS11
SS13
SS15
Future
4.16 kV Exp. Bus (Starboard)

Generation

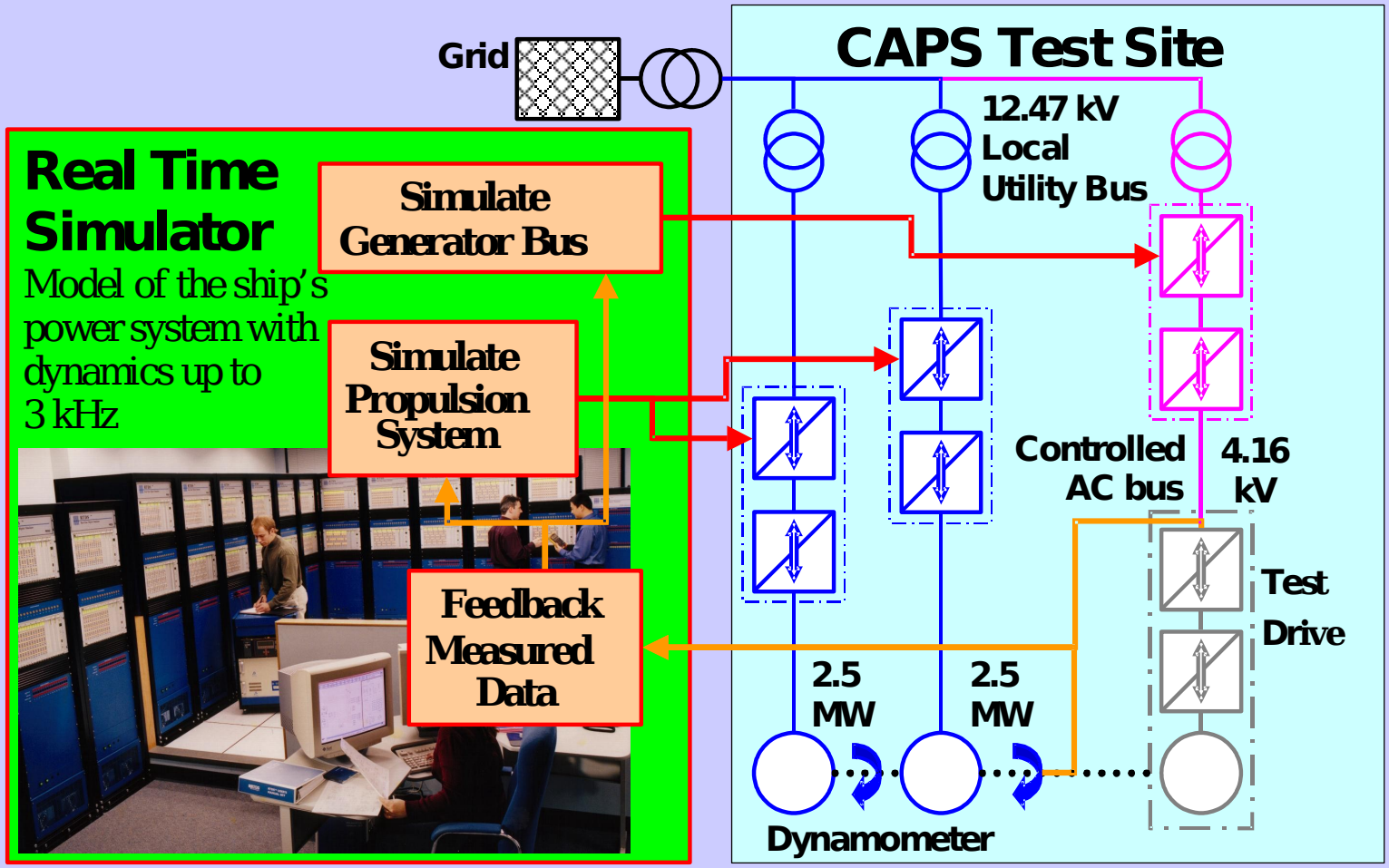
Provides capability to investigate generator-load interactions, control systems, stability controls independent of utility bus system.

- 2 – 2.5 MW Gas Turbine Generators

Status

- Preliminary Design under way.
- Procurement planned for 2004-2005
- Operational in 2005

Real-Time Simulation



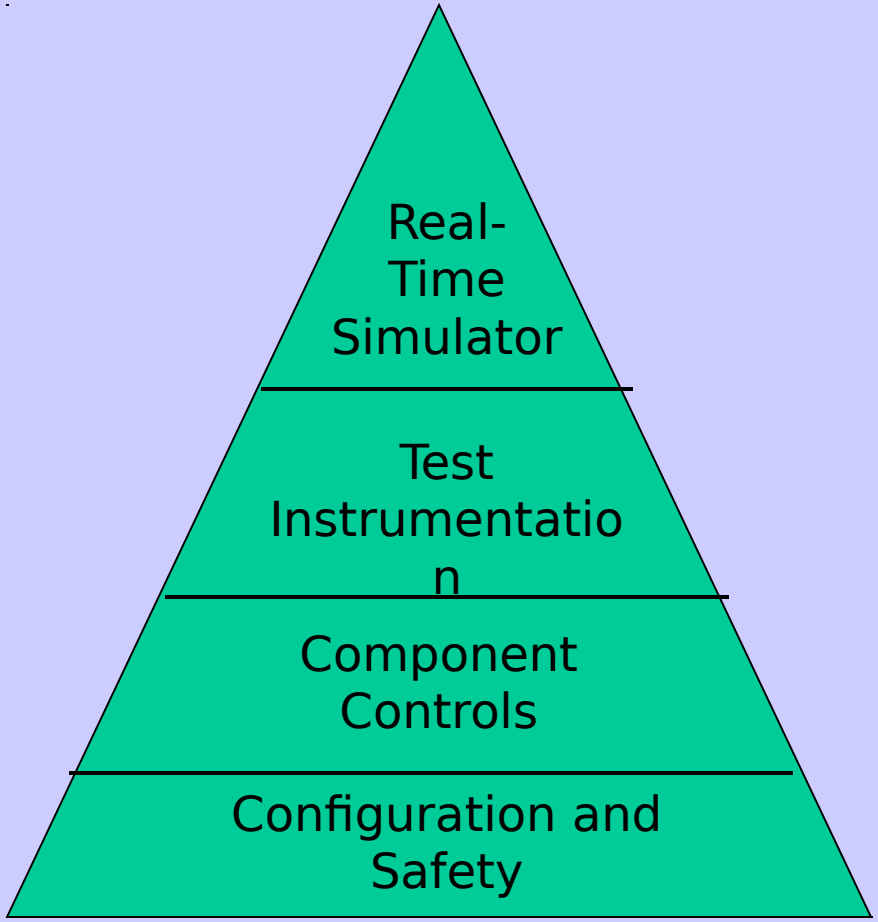
Real Time Simulation

- Capablity – 50 us time step- good transient fidelity to about 3 to 5 kHz.
- Control of Advanced Prototype Test Facilities to represent full systems by emulating portions in the real time simulation.
- Capability to evaluate and test control systems via Hardware-in-the-Loop operations
- Capability to study power system interactions in depth by emulating components that do not yet exist.

Real-Time Simulation Status

- Real Time Simulator has been delivered and passed acceptance tests.
- Beginning initial H-I-L trials with small components
- 15KW Dynamometer ordered to be delivered in December 2003 for initial investigation of H-I-L operations
- Plan to integrate with 5 MW dynamometer in summer of 2003

Facility Control Strategy

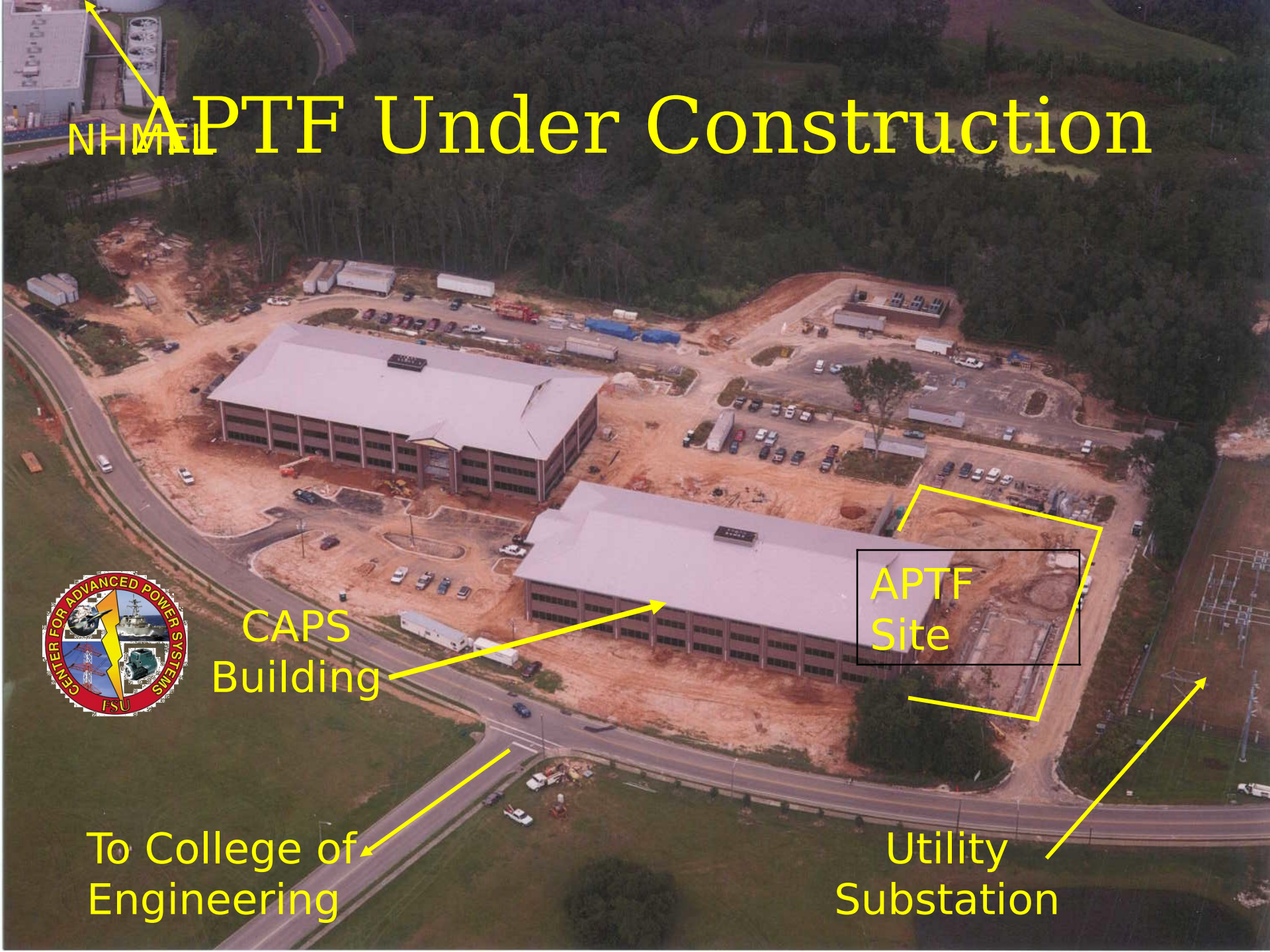


Real Time Simulator control of test and facility hardware to emulate actual system conditions

Data acquisition system to record component and system performance

Provide control and protection of components – responds to simulator control

Master supervisory control – facility safety and operational limits.


NHMFL
APTF Under Construction
CAPS
Building
APTF
Site
To College of
Engineering
Utility
Substation

Relationship of APTF to AEPS Thrust

The Advanced Prototype Test Facilities directly address a number of the Thrust Opportunities:

- Funding, Education & a National Plan for Electric Power Technology infrastructure
- Training of power experts, world class facility attracts US Students.
- Major world class initiative in experimental facility development
- Major implementation of Simulation/Stimulation analysis with hardware in the loop to explore/validate stablity & control issues and models.
- Superconducting and cryogenic systems technologies to improve efficiency and power density.

The APTF is the essential tool to improving the understanding of the physics of electrical power systems

Relationship of CAPS Research to AEPS Thrust

Academic Program – addresses critical shortage of power experts.

HTS Transformer –superconducting power equipment and cryogenic technology is key to energy density and thermal management issues.

HTS Materials – focus on AC loss is key to long term successful application of superconductors to power systems.

Simulation and Modeling – addresses the issues of adequate tools for modeling stability, controlability and fault recognition

Controls - Program in intelligent agents is directly focused on fundamental issue of energy management and control.

Power Systems – Focuses on simulation and modeling capability for broad based power systems with novel components.